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February 29, 2000

BOX PATENT APPLICATION
Assistant Commissioner for Patents
Washington, D.C. 20231

Re: Mark BURTON
SYNCHRONIZATION IN DIGITAL DATA TRANSMISSION SYSTEMS
Our Ref. Q58064

Dear Sir:

Attached hereto is the application identified above including 14 sheets of the specification, claims, 4 sheets of drawings, executed Assignment and PTO 1595 form, and executed Declaration and Power of Attorney. Also enclosed is the Information Disclosure Statement with form PTO-1449 and references.

The Government filing fee is calculated as follows:

Total claims	11 - 20	=		x	\$18.00	=	\$0.00
Independent claims	1 - 3	=		x	\$78.00	=	\$0.00
Base Fee							\$690.00
TOTAL FILING FEE							\$690.00
Recordation of Assignment							\$40.00
TOTAL FEE							\$730.00

Checks for the statutory filing fee of \$690.00 and Assignment recordation fee of \$40.00 are attached. You are also directed and authorized to charge or credit any difference or overpayment to Deposit Account No. 19-4880. The Commissioner is hereby authorized to charge any fees under 37 C.F.R. §§ 1.16 and 1.17 and any petitions for extension of time under 37 C.F.R. § 1.136 which may be required during the entire pendency of the application to Deposit Account No. 19-4880. A duplicate copy of this transmittal letter is attached.

Priority is claimed from March 6, 1999 based on Great Britain Application No. 9905194.8. The priority document is enclosed herewith.

Respectfully submitted,
SUGHRUE, MION, ZINN,
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Attorneys for Applicant

By: J. Frank Osha
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SYNCHRONIZATION IN DIGITAL DATA TRANSMISSION SYSTEMS

BACKGROUND OF THE INVENTION

1. Field of the Invention:

5 The present invention relates to digital data transmission, and more particularly to digital data decoders.

2. Description of the Related Art:

Reference is made to US patents 5,838,672 to Ranta
10 and 5,479,444 to Malkamaki et al and "Mobile Radio Communications" published by John Wiley & Sons, Raymond Steele (Ed.) for a description of the prior art and technological background.

The following description is based on the GSM
15 cellular communications system for which the invention is of particular utility. It will be apparent to those skilled in the art, however, that the invention may be applied to other systems of digital data transmission.

When a mobile phone terminal is to be used to
20 communicate via a network, it must first obtain synchronization with the network. This is essentially a three step passive process. The mobile terminal must synchronize with the base station transmission in time, then frequency and then must read control information
25 to enable the location updating procedure. In the following description it is assumed that a channel

containing a broadcast control channel (BCCH) has been chosen.

The channel estimation method according to a prior art arrangements is shown in the flow chart of Fig. 1.

5 At step 401, initially a Frequency Correction Burst (FCB), which is an unmodulated carrier, is sought by scanning of the wanted channel. When a FCB has been received the burst is used to provide coarse time and frequency synchronizations e.g. by means of a
10 narrowband filter at step 402. The coarse time and frequency synchronizations are applied to the next stage of the synchronization process.

When a Synchronization Burst (SB) is received at step 403, it is processed and used to refine both time
15 and frequency synchronization at step 404, 405. The SB contains channel coded information which enables the mobile terminal to access the network. After successfully decoding the SB the mobile terminal is fully synchronized to the network and communications
20 can proceed.

The current arrangements for Synchronization Burst equalization are limited in performance by their intolerance to residual frequency offsets arising from the estimate of the frequency derived from the
25 Frequency Burst. What this means in practice is that when a noisy estimate of the frequency offset is

derived from the Frequency Burst processing, then the probability of successful decoding of the Synchronization burst is significantly reduced. Under these conditions the mobile terminal is likely to fail to synchronize with the network.

Existing arrangements for Synchronization Burst decoding are based on the conventional techniques of channel estimation, equalization and convolutional decoding. The channel estimation technique used depends upon calculating the cross-correlation of the expected 64 symbol training sequence with the 64 symbol training sequence received in the synchronization burst. This cross Correlation gives an estimate of the propagation channel. For a channel where no frequency error is present such existing arrangements provide a satisfactory channel estimate.

This is typically not the case, however, on a real fading channel when the mobile terminal is trying to gain initial synchronization with the network. For a fading channel a residual frequency error is carried over from the imperfect frequency estimation derived by the initial Frequency Burst detection. A residual frequency error on the received symbols of the Synchronization Burst is manifest as a constant, accumulating phase offset as a function of time.

This in turn affects the channel estimate obtained

by performing a cross correlation of the received Synchronization Burst symbols with the expected training sequence so as to cause a degradation of the equalization procedure. When the bit error rate for the equalized burst exceeds that which can successfully be tolerated by the channel coding used to protect the information contained in the SB, then the synchronization will fail.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a channel estimation method which is capable of performing a channel estimation with successfully even on a fading channel.

According to the present invention there is provided a channel estimation method for a digital telecommunication station in which a received training sequence is cross correlated with a selected subset of an expected training sequence to obtain a channel estimate and a frequency error estimate is derived from said channel estimate and the frequency error of the received burst is corrected in accordance with said frequency error estimate.

The above and other objects, features and advantages of the present invention will become apparent from the following description with reference

to the accompanying drawings which illustrate examples of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Fig.1 is a flow diagram showing a prior art Synchronization Burst decoder;

Fig 2 is a flow diagram showing a Synchronization Burst decoder according to the present invention;

10 Fig.3 shows a GSM Synchronization Burst training sequence; and

Fig.4 is a Doppler tracking phase locked loop.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 A means for an improvement over the prior art methods in the tolerance to residual frequency error of the Synchronization Burst decoding process is illustrated in the flow diagram of Fig.2. The frequency burst detection (step 101) and coarse time and frequency estimates (step 102) are obtained in the
20 usual manner in accordance with prior art methods.

A GSM training sequence is shown in Fig.3 with each of the symbols labelled 1 to 64. It is convenient here to show the training sequence as comprising three sections labelled A, B and C. The full sequence of
25 symbols from 1 to 64 is transmitted consecutively, however, and Fig.3 serves to illustrate as section B

the 24 symbol sub set used to obtain the frequency error estimate. The symbols 1 through 64 would be the training sequence expected to be received by the mobile phone terminal.

5 Returning to Fig.2, at capture of the
synchronization burst (step 103) the received training
sequence is cross correlated with the subset B of the
expected training sequence. This cross correlation
makes use of the auto correlation property of a subset
10 B of the Synchronization Burst training sequence.
Although this 24 symbol sequence is not perfectly auto
correlated, it is almost so.

Therefore the cross correlation of the received
symbols is performed using the 24 symbol subset B of
15 the training sequence. This cross correlation provides
a channel estimate which has been generated from a more
temporally localized sequence of received symbols. The
effects arising from the phase error due to a residual
frequency offset are therefore reduced and the channel
20 estimate is better than it would have been had the full
64 symbols of the training sequence been used.

The next step 104 is to obtain a frequency error
estimate using the 24 symbol based channel-estimate in
conjunction with the *a priori* 64 symbol training
25 sequence. This can be achieved by using a standard
technique such as a second order phase locked loop

(PLL), locked in frequency and phase to the reference (expected) training sequence symbols. A block diagram of a suitable PLL is shown in Fig.4.

The Doppler Tracking PLL of Fig.4 in the equalizer is of the decision directed 2nd order type. This provides a PLL which is locked in both phase and frequency to the reference symbols. The PLL provides a phase correction to the next received symbol to be equalized.

The characteristic equations describing the PLL are:

$$\phi(n-1) = \phi(n-2) + f(n-1) + k_1 \theta(n-1)$$

$$f(n-1) = f(n-2) + k_2 \theta(n-1)$$

where k_1 is the "phase" loop gain and k_2 is the "frequency" loop gain. The open loop transfer function is given by:

$$\frac{\phi(z)}{\theta(z)} = \frac{k_2}{1 - 2z^{-1} + z^{-2}} + \frac{k_1}{1 - z^{-1}}$$

The values

$$k_1 = 0.08$$

$$k_2 = 0.08/29.0$$

for the loop gains k_1 and k_2 , were determined by trial

and error using a Matlab model, where the main criterion used was the convergence of the loop within the available number of symbols in a Normal Burst.

In this example, for Normal Burst equalization the PLL is used solely for phase correction during equalization. For Synchronization Bursts, however, the PLL is used in addition for performing an initial frequency estimate from the training sequence. This initial frequency estimate is then used to apply a frequency correction to the set of received symbols before equalization proper is performed.

After application of the chosen frequency estimate algorithm the resultant frequency estimate is then used to correct all symbols of the received burst at step 105. The performance of the frequency estimate algorithm must exceed the performance of the FCB frequency estimation algorithm so that the applied correction will improve the residual frequency error present in the corrected received symbols. After the frequency correction has been applied to the whole buffer of received symbols a second channel estimate is calculated at step 106.

This second channel estimate is made by taking the cross correlation of the 64 frequency corrected symbols of the received training sequence and the 64 symbols of the expected training sequence of the Synchronization

Burst. This channel estimate should therefore be better than the 24 symbol channel estimate previously calculated and better also than the 64 symbol channel prior art estimate usually obtained. This is due to
5 the reduction of residual frequency error and use of all the symbols of the training sequence in the cross correlation. Equalization of the received SB then proceeds in the usual manner at step 106 using the frequency corrected symbols. The frequency corrected
10 symbols are used to refine the time and frequency synchronizations at step 107.

Proposals exist for varying or adapting training sequences e.g. as described in US 5,479,444, US 5,838,672 and WO 9807291. A selected subset of an
15 adaptive training sequence may be used for cross correlation with an expected training sequence to provide an initial estimate of frequency error for correction of the frequency of the received burst in accordance with the initial estimate of the frequency
20 error.

A training sequence may also be adapted to provide a subset of the training sequence with improved auto correlation properties.

While a preferred embodiment of the present
25 invention has been described using specific terms, such description is for illustrative purposes only, and it

is to be understood that changes and variations may be made without departing from the spirit or scope of the following claims.

What is claimed is:

1. A channel estimation method for a digital telecommunication station, comprising the steps of:

detecting a frequency correction burst by scanning of a wanted channel;

5 providing time and frequency synchronizations by using said frequency correction burst;

receiving a synchronization burst;

cross correlating received training sequence contained in said synchronous burst with a selected
10 subset of an expected training sequence to obtain a channel estimate;

deriving a frequency error estimate from said channel estimate;

correcting the frequency error of the received
15 burst in accordance with said frequency error estimate;

equalizing the received synchronous burst; and

providing time and frequency synchronizations again by using said corrected frequency correction burst.

2. A channel estimation method according to claim 1, wherein the received training sequence is part of the signal within a synchronization burst transmitted by a base station of a cellular telephone
5 network.

3. A channel estimation method according to claim 2, wherein the received training sequence is the 64 bit training sequence of the GSM system.

5 4. A channel estimation method according to claim 3, wherein the selected subset comprises the 21st through to the 44th symbols of the training sequence.

10 5. A channel estimation method according to claim 1, wherein the training sequence is an adaptive training sequence.

15 6. A channel estimation method according to claim 2, wherein the training sequence is an adaptive training sequence.

20 7. A channel estimation method according to claim 1, wherein the selected subset is an adaptive subset.

8. A channel estimation method according to claim 2, wherein the selected subset is an adaptive subset.

25 9. A channel estimation method according to claim 6, wherein the selected subset is an adaptive

subset.

10. A channel estimation method according to
claim 1, wherein the frequency error estimate is
5 obtained by a Doppler tracking phase locked loop.

11. A channel estimation method according to
claim 2, wherein the frequency error estimate is
obtained by a Doppler tracking phase locked loop.

ABSTRACT OF THE DISCLOSURE

A channel estimation method for a digital telecommunication station is disclosed. A frequency correction burst is sought by scanning of the wanted channel. The frequency correction burst is used to provide coarse time and frequency synchronizations. A synchronization burst is received. Calculating the cross-correlation of the expected training sequence with the training sequence contained in said synchronous burst to obtain a channel estimate. A frequency error estimate is derived from the channel estimate, and the frequency error of the received burst is corrected in accordance with said frequency error estimate. The received synchronous burst is equalized. The frequency corrected symbols are used to refine the time and frequency synchronizations.

Fig. 1
PRIOR ART

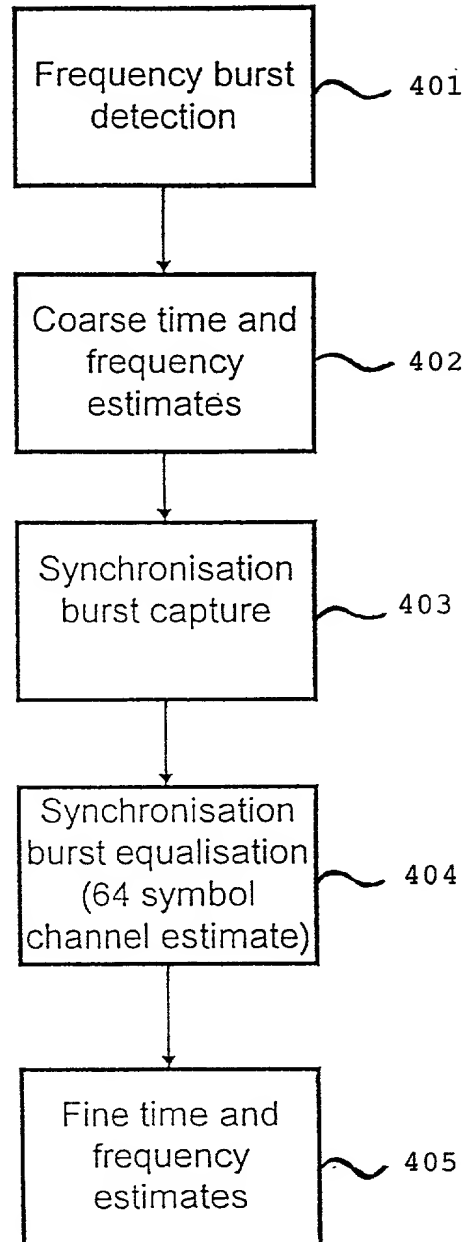
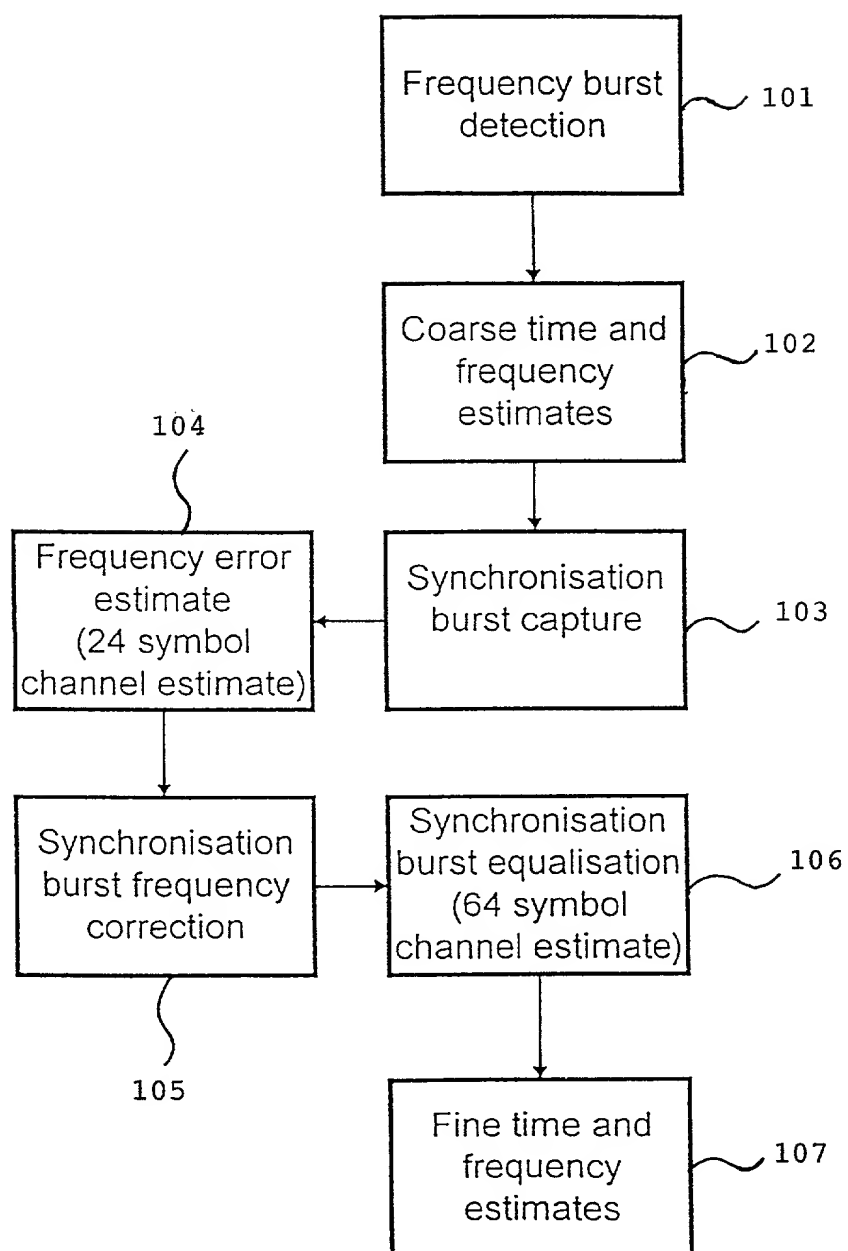
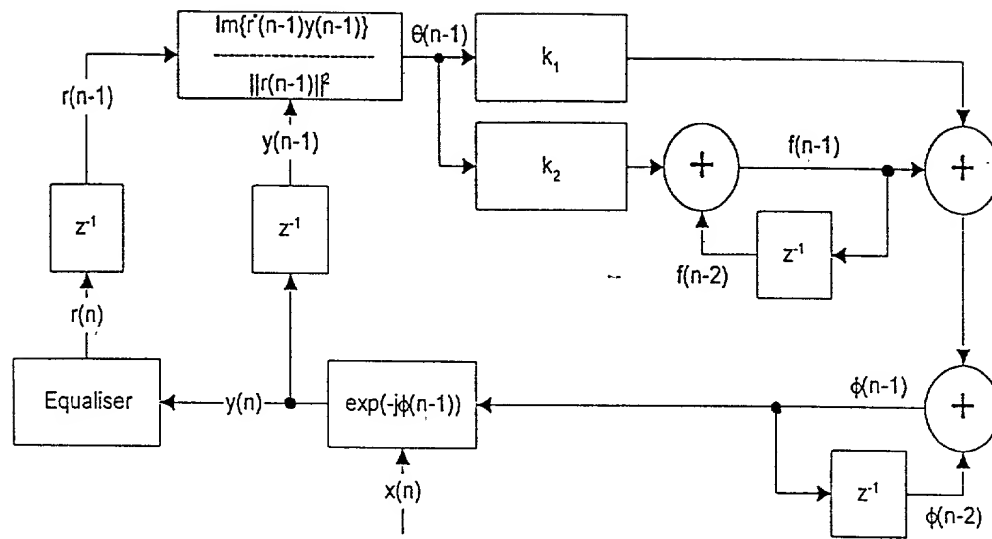


Fig. 2



F i g . 4



DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; that I verily believe I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural names are listed below) of the subject matter claimed and for which a patent is sought in the application entitled:

SYNCHRONIZATION IN DIGITAL DATA TRANSMISSION SYSTEMS

which application is:

X the attached application
(for original application)

_____ application Serial No. _____
filed _____, and amended on _____

(for declaration not accompanying application)

that I have reviewed and understand the contents of the specification of the above-identified application, including the claims, as amended by any amendment referred to above; that I acknowledge my duty to disclose information of which I am aware which is material to the patentability of this application under 37 C.F.R. 1.56, that I hereby claim foreign priority benefits under Title 35, United States Code §119, §172 or §365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified on said list any foreign application for patent or inventor's certificate on this invention having a filing date before that of the application on which priority is claimed:

Application Number	Country	Filing Date	Priority Claimed (yes or no)
9905194.8	The United Kingdom	March 6, 1999	yes

I hereby claim the benefit of Title 35, United States Code §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in a listed prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge my duty to disclose any information material to the patentability of this application under 37 C.F.R. 1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Filing Date	Status (patented, pending, abandoned)
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I hereby appoint John H. Mion, Reg. No. 18,879; Donald E. Zinn, Reg. No. 19,046; Thomas J. Macpeak, Reg. No. 19,292; Robert J. Seas, Jr., Reg. No. 21,092; Darryl Mexic, Reg. No. 23,063; Robert V. Sloan, Reg. No. 22,775; Peter D. Olexy, Reg. No. 24,513; J. Frank Osha, Reg. No. 24,625; Waddell A. Biggart, Reg. No. 24,861; Robert G. McMorro, Reg. No. 19,093; Louis Gubinsky, Reg. No. 24,835; Neil B. Siegel, Reg. No. 25,200; David J. Cushing, Reg. No. 28,703; John R. Inge, Reg. No. 26,916; Joseph J. Ruch, Jr., Reg. No. 26,577; Sheldon I. Landsman, Reg. No. 25,430; Richard C. Turner, Reg. No. 29,710; Howard L. Bernstein, Reg. No. 25,665; Alan J. Kasper, Reg. No. 25,426; Kenneth J. Burchfiel, Reg. No. 31,333; Gordon Kit, Reg. No. 30,764; Susan J. Mack, Reg. No. 30,951; Frank L. Bernstein, Reg. No. 31,484; Mark Boland, Reg. No. 32,197; William H. Mandir, Reg. No. 32,156; Scott M. Daniels, Reg. No. 32,562; Brian W. Hannon, Reg. No. 32,778 and Abraham J. Rosner, Reg. No. 33,276, my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith, and request that all correspondence about the application be addressed to **SUGHRUE, MION, ZINN, MACPEAK & SEAS**, 2100 Pennsylvania Avenue, N.W., Washington, D.C. 20037-3202.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date January 17, 2000

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